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ETHNICITY IDENTIFICATION THROUGH HAND DIMENSIONS: A STUDY IN NORTH INDIA

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ABSTRACT
A vital important aspect in forensic anthropology is the identification of ethnicity of unknown individual or skeletal remains in addition to stature and sex. However, there is very limited number of study in the aspect of ethnicity identification. **Objectives:** The aim of this paper is to develop discriminant function formulae to determine ethnic groups from hand dimensions of North Indian Gujars and Jats. **Materials and Methods:** The individuals participated in the study belong to the northern part of India. The sample is composed of 161 Gujar males and 160 Gujar females and 155 Jat males and 152 Jat females. A total of 23 hand dimensions were utilized and discriminant function module of SPSS statistical software was used to analyse the data. **Results and Discussion:** Using 23 standard hand dimensions, average accuracies of 73% were obtained to discriminate the ethnic groups. This accuracy was about the same (72%) as obtained through multivariate function analysis when a “leave-one-out classification” technique was applied to the samples. A posterior probability of 0.59 was found in as much as 92% of the sample. Stepwise discriminant function formulae were also derived for population specific standards and for the cases where fragmentary remains recovered for identification.

KEYWORDS: Human identification, Ethnicity, Discriminant function analysis, Hand anthropometry, North Indian population groups.

INTRODUCTION
In any analysis of a forensic case, the investigation proceeds with the identification of the evidences encountered in crime scene and the primary identity indicators are age, sex, stature and race.[1,2] Much research has been conducted in the field of stature estimation[3,13] and sex determination.[14,23] However, there are limited numbers of study conducted in the field of ethnicity prediction. Jacobson (1978) conducted a study on race differences among South African blacks and whites using radiographs of the craniofacial skeletons.[24] Kieser and Groeneveld (1989) focussed on South African blacks and whites and Lengua Indians of Paraguay using discriminant function analysis of dental dimensions.[25] Iscan and Steyn (1999) conducted a study on determination of population affinity in South Africans using craniometric parameters.[26] Authors also argued that the criteria used for the establishment of identity characteristics are relevant to that particular specific group and not applicable to another group due to changes in robusticity, body build, growth pattern, degree of sexual dimorphism and environmental changes. Thus the population specific formulae for identity authentication is motivated and conducted around the world.[27,28] Literature suggests that different parts of body or bones can be utilized for the determination of identity parameters such as skull, long bones, pelvis, facial measurements, foot parameters and hand measurements. But in forensic scenarios, we frequently encountered fingerprints, blood traces, foot marks and hand impression or prints. Hand measurements are proved to be a good predictor of stature[5,6] and are sexually dimorphic.[22,23] Thus in the present study an attempt has been made to differentiate people of unknown racial origin on the basis of hand anthropometric measurements by developing specific hand discriminatory equations for assessing ethnicity or population affinity of North Indian Gujars and Jats.

MATERIALS AND METHODS
Participants
A total of 628 participants (161 Gujar males and 160 Gujar females and 155 Jat males and 152 Jat females) of North Indian population were recruited to conduct the research study. Gujars was collected from villages namely Usmanpur, Ghonda, Ghamari and Ghari Mendu under district North – East, Delhi and Jats were collected from the villages of Pilana tehsil under district Baghpat in the state of Uttar Pradesh. Each participant were prior informed about the research study and the related

measurement procedures and were assured about the confidentiality of the data they provided and were required to sign a consent form before participating in the study. Participants with any medical history of hand or wrist or fingers were excluded from the research study.

Procedure and Measurements

The hands of the participants were placed on a flat surface with the palm facing upward, forearm in line with the middle finger and the fingers extended maximally. Hand variables were measured in centimetres with the help of sliding calipers following standard anthropometric techniques suggested by Martin & Saller (1959) and Singh and Bhasin (1968).[29,30] All the measurements were obtained from both the right and left hand and repeated three times for accuracy and mean value was taken for statistical analysis. All the measurements were collected by one observer in the same way and under the same conditions to avoid inter-observer errors. A total of twenty (23) hand dimensions were utilized to conduct the study[30,31] and these were

1. *Hand Length* (HL): The distance between the mid-point of inter-stylion to the tip of the middle finger.
2. *Hand Breadth I* (HB-I): The straight distance between the most laterally placed point at the distal inter-phalangeal joint of the index finger to the most medially placed point on the ulnar side of ring finger.
3. *Hand Breadth II* (HB-II): The straight distance between the most laterally placed point at the proximal inter-phalangeal joint of the index finger to the most medially placed point on the ulnar side of little finger.
4. *Hand Breadth III at metacarpal* (HB-III): The distance between the most lateral point on the index finger metacarpal to the most medial point on the little finger metacarpal.
5. *Maximum Hand Breadth* (MHB): It measures the maximum breadth of the hand across the thumb.
6. *Palm Length* (PL): The distance between the mid-point of the inter-stylion to the proximal flexion crease of the middle finger.
7. *Palm Breadth* (PB): Palm breadth measured across the palm of the hand at the level of the junction between the palm and the fingers, excluding the thumb.
8. *Finger Length – I* (FL-I): The distance between the proximal flexion crease of the finger to the tip of the thumb.
9. *Finger Length – II* (FL-II): The distance between the proximal flexion crease of the finger to the tip of the index finger.
10. *Finger Length – III* (FL-III): The distance between the proximal flexion crease of the finger to the tip of the middle finger.
11. *Finger Length – IV* (FL-IV): The distance between the proximal flexion crease of the finger to the tip of the ring finger.
12. *Finger Length – V* (FL-V): The distance between the proximal flexion crease of the finger to the tip of the little finger.
13. *Finger Breadth – I* (FB-I): The distance between the most lateral point on the proximal inter-phalangeal joint of the thumb to the most medial point.
14. *Finger Breadth – II* (FB-II): The distance between the most lateral point on the proximal inter-phalangeal joint of the index finger to the most medial point.
15. *Finger Breadth – III* (FB-III): The distance between the most lateral point on the proximal inter-phalangeal joint of the middle finger to the most medial point.
16. *Finger Breadth – IV* (FB-IV): The distance between the most lateral point on the proximal inter-phalangeal joint of the ring finger to the most medial point.
17. *Finger Breadth – V* (FB-V): The distance between the most lateral point on the proximal inter-phalangeal joint of the little finger to the most medial point.
18. *Wrist Breadth* (WB): The distance between the most lateral point and the most medial point of the wrist.
19. *Hand Index* (HI): It is calculated as the percentage variation between the hand breadth to the hand length.
20. *Palm Index* (PI): It is calculated as the percentage variation between the palm breadth to the palm length.
21. *All Finger Length* (AFL): It is the summation of the length of all the fingers.
22. *All Finger Breadth* (AFB): It is the summation of the breadth of all the fingers.
23. *All Finger Index* (AFI): It is calculated as the percentage variation between all finger breadth to the all finger length.

Statistical Analysis

SPSS 20.0 was employed for the statistical analysis of the research data. Standard descriptive statistics were calculated with means and standard deviations and a one-way ANOVA analysis to assess the male – female differences for the variables were observed at $p < 0.001$ as level of significance. Stepwise discriminant function statistics by Fischer[33] were performed using all hand variables using Wilk's lambda minimization procedure (with F =3.84 to enter and F = 2.71 to remove). In addition, five combinations of hand dimensions such as length (a total of 8 variables), breadth (a total of 12 variables), index (a total of 3 variables), finger (a total of 10 variables) and hand shape (a total of 8 variables) were chosen for a stepwise discriminant procedure to create formulae that can be used under different circumstances of availability of the evidences. The following analyses were run: stepwise discriminant analysis using all twenty-three measurements; step analysis using length variables; Step analysis using breadth variables; Step analysis using Index variables; step analysis using finger variables; and lastly step analysis using hand shape variables. Discriminant function analysis calculates the pooled within-group covariance matrix, eigenvalues, canonical correlations, wilk's lambda, significance levels of all the generated discriminant functions, values of the standardized and unstandardized discriminant function coefficients and group centroids. Accuracies of the functions were recorded including cross-validated using a leave-one-out procedure.

RESULTS

Table 1: Means, Standard deviations and Univariate F-ratios for North Indian Gujars and Jats.

Variables[a] (cm)	Gujar		Jat		Univariate F-ratio[b]
	Mean	Std. Dev.	Mean	Std. Dev.	
Males	***n* = 161**		***n* = 155**		
HL	18.708	0.960	18.935	0.928	4.556[c]
HB-I	5.178	0.358	5.206	0.315	.576
HB-II	7.558	0.546	7.615	0.501	.937
HB-III	8.583	0.495	8.534	0.518	.740
PL	10.606	0.688	10.719	0.667	2.226
PB	8.602	0.586	8.398	0.512	10.814[e]
FL-I	6.553	0.417	6.584	0.443	.413
FL-II	7.232	0.494	7.370	0.438	6.878[d]
FL-III	8.017	0.557	8.035	0.563	.074
FL-IV	7.432	0.498	7.625	0.462	12.676[e]
FL-V	6.014	0.491	6.167	0.447	8.387[e]
FB-I	2.094	0.155	2.160	0.134	16.122[e]
FB-II	1.917	0.120	1.925	0.108	.364
FB-III	1.959	0.120	1.978	0.109	2.168
FB-IV	1.854	0.122	1.860	0.185	.115
FB-V	1.659	0.118	1.690	0.123	5.101[c]
WB	5.793	0.343	5.652	0.324	14.176[e]
MHB	10.696	0.673	10.565	0.571	3.509
HI	45.916	2.186	45.112	2.879	7.859[d]
PI	81.281	5.487	78.482	4.764	23.371[e]
AFL	35.248	2.121	35.801	1.910	5.923[d]
AFB	9.483	0.542	9.565	0.915	.946
AFI	26.968	1.760	26.786	2.823	.477
Females	**n = 160**		**n = 152**		
HL	17.264	0.845	17.334	0.894	.494
HB-I	4.714	0.385	4.686	0.455	.351
HB-II	6.941	0.511	6.961	0.429	.130
HB-III	7.793	0.474	7.787	0.455	.014
PL	9.664	0.557	9.754	0.631	1.770
PB	7.638	0.454	7.518	0.484	5.085[c]
FL-I	6.069	0.424	5.967	0.447	4.246[c]
FL-II	6.763	0.396	6.772	0.463	.033
FL-III	7.458	0.446	7.456	0.468	.002
FL-IV	6.929	0.480	6.985	0.494	1.037
FL-V	5.578	0.449	5.609	0.599	.274
FB-I	1.939	0.135	1.956	0.144	1.184
FB-II	1.766	0.119	1.746	0.126	1.954
FB-III	1.778	0.120	1.780	0.116	.037
FB-IV	1.683	0.113	1.675	0.099	.441
FB-V	1.524	0.116	1.513	0.118	.712
WB	5.238	0.291	5.098	0.311	17.044[e]
MHB	9.577	0.524	9.509	0.562	1.234
HI	45.190	2.698	44.977	2.832	.466
PI	79.201	5.311	77.801	5.471	5.262[c]
AFL	32.797	1.704	32.822	2.044	.014
AFB	8.689	0.505	8.680	0.497	.025
AFI	26.543	1.751	26.512	1.747	.025

[a]These variables are used in the calculation of Functions, [b]df 314 for males and 310 for female hand variables, [c, d, e]Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

Table 2: Stepwise discriminant function analysis of hand variables for North Indian males of Gujars and Jats.

Step	Variables entered	Wilk's Lambda	Equiv. F-ratio*	Degrees of freedom
***Males*[a]**				
Function 1 (Length Variables)				
1.	FL-IV	0.961	12.676	314
2.	FL-III	0.903	16.840	313
Function 2 (Breadth Variables)				
1.	FB-I	0.951	16.122	314
2.	WB	0.851	27.376	313
3.	PB	0.830	21.307	312
4.	FB-V	0.817	17.452	311
Function 3 (Index Variables)				
1.	PI	0.931	23.371	314
Function 4 (Finger Variables)				
1.	FB-I	0.951	16.122	314
2.	FL-IV	0.930	11.840	313
3.	FL-III	0.875	14.894	312
4.	FB-II	0.860	12.651	311
Function 5 (Hand Shape Variables)				
1.	WB	0.957	14.176	314
2.	HL	0.909	15.712	313
3.	PB	0.884	13.597	312
4.	MHB	0.768	23.440	311
Function 6 (All Hand Variables)				
1.	PI	0.931	23.371	314
2.	FB-I	0.876	22.167	313
3.	WB	0.795	26.867	312
4.	FL-IV	0.765	23.839	311
5.	FL-III	0.726	23.380	310

* *All significant at P < 0.001.*

[a]*Variables not selected for **Function 1** include hand length, palm length, finger length – I, II, V, all finger length; **Function 2** include Hand breadth – I, II, III, finger –II, III, IV, maximum hand breadth, all finger breadth; **Function 3** include hand index and all finger index; **Function 4** include finger length – I, II, V, finger breadth – III, IV, V; **Function 5** include hand breadth – I, II, III, palm length; **Function 6** include hand length, hand breadth – I, II, III, palm length, palm breadth, finger length – I, II, III, finger breadth – II, III, IV, V, hand index, maximum hand breadth, all finger length, all finger breadth, all finger index.*

The descriptive statistics which includes mean, standard deviations and univariate F-ratios for the twenty-three hand variables of North Indian Gujars and Jats are presented in Table 1. Males show significantly higher values than females for all the hand variables. In terms of handedness or bilateral or right and left hand variation, the difference was not statistically significant and thus average of right and left hand dimension was computed for further statistical analysis. The F-ratios indicated that the mean differences between the hand dimensions of the ethnic groups were statistically significant for the majority of variables in both the sexes. The most significant differences in hand variables were observed in wrist breadth ($p < 0.001$) in both sexes.

Table 3: Stepwise discriminant function analysis of hand variables for North Indian females of Gujars and Jats.

Step	Variables entered	Wilk's Lambda	Equiv. F-ratio*	Degrees of freedom
Females [a]				
Function 1 (Length Variables)				
1.	FL-I	0.986	4.246	310
Function 2 (Breadth Variables)				
1.	WB	0.948	17.044	310
2.	FB-III	0.921	13.187	309
Function 3 (Index Variables)				
1.	PI	0.983	5.262	310
Function 4 (Finger Variables)				
1.	FL-I	0.986	4.246	310
Function 5 (Hand Shape Variables)				
1.	WB	0.948	17.044	310
2.	HB-II	0.927	12.248	309
3.	PL	0.910	10.187	308
Function 6 (All Hand Variables)				
1.	WB	0.948	17.044	310
2.	FB-III	0.921	13.187	309
3.	FL-IV	0.908	10.352	308
4.	PB	0.893	9.162	307
5.	FL-I	0.880	8.368	306
6.	HB-II	0.867	7.766	305
7.	PL	0.856	7.317	304

* *All significant at* $P < 0.001$

[a] *Variables not selected for* ***Function 1*** *include hand length, palm length, finger length – II, III, IV, V, all finger length;* ***Function 2*** *include Hand breadth – I, II, III, palm breadth, finger – I, II, IV, V maximum hand breadth, all finger breadth;* ***Function 3*** *include hand index and all finger index;* ***Function 4*** *include finger length – II, III, IV, V, finger breadth – I, II, III, IV, V;* ***Function 5*** *include hand length, hand breadth – I, III, palm breadth, maximum hand breadth;* ***Function 6*** *include hand length, hand breadth I, III, finger length - II, III, V, finger breadth – I, II, IV, V, hand index, palm index, maximum hand breadth, all finger length, all finger breadth, all finger index.*

Table 2 & 3 shows the results of the stepwise discriminant function analysis of the hand variables for North Indian males of Gujars and Jats. The Wilk's lambda determines the strength of a given variable in the stepwise analysis and also the order in which the variables enter the function (Variables which are not selected for the six stepwise functions are listed below the table). In Function 1, out of the 8 length variables entered in stepwise procedure, 2 variables were selected for males and 1 for females. Finger length – IV was chosen first in males and finger length – I in females. In Function 2, out of 12 breadth variables participated, 4 variables were selected for males and only 2 variables for females. Finger breadth – I was chosen first among males and wrist breadth among females. Out of the 3 index variables entered for Function 3, only palm index was selected for both the sexes. In Function 4, of the 10 finger variables, 4 variables were selected in case of males whereas only one variable in case of females. Finger breadth – I was chosen first both in males and females. In Function 5, out of 8 hand shape variables entered, 4 participated in stepwise analysis in males and 3 in females. Wrist breadth was first in order for both the males and females. When all the 23 hand variables entered in Function 6, a total of 5 variables for males and 7 variables for females were selected for stepwise discriminant function analysis with palm index selected first for males and wrist breadth for females.

Canonical discriminant function coefficients such as unstandardized, standardized and structure coefficients, constants and sectioning points for hand variables selected by the stepwise discriminant function analysis for males and females appear in Table 4 and Table 5 respectively. Standardized coefficients indicate the relative contribution of a variable to the function or the overall classification.

In the first Function, ring finger length makes the greatest contribution followed by middle finger length; in Function 2, finger breadth at proximal inter-phalangeal joint of the thumb made the greatest contribution followed wrist breadth, palm breadth and finger breadth at proximal inter-phalangeal joint of the little finger contributes the least; in Function 4, ring finger length made the greatest contribution followed by middle finger length, finger breadth at proximal inter-phalangeal joint of the thumb and finger breadth at proximal inter-phalangeal joint of the index finger contributes the least; in Function 5, palm breadth made the greatest contribution followed by maximum hand breadth, wrist breadth and hand length contributes the least and lastly in

Function 6, ring finger length made the greatest contribution followed by middle finger length, wrist breadth, finger breadth at proximal inter-phalangeal joint of the thumb and palm index contributes the least in case of males of North Indian Gujars and Jats.

Table 4: Canonical discriminant function coefficients and sectioning points for hand variables selected by the stepwise sub-routine for males.

Functions and Variables	Unstandardized coefficient	Standardized Coefficient	Structure Coefficient	Gujar and Jat group centroids
Males[a]				
Function 1 (Length Variables)				
FL-IV	3.616	1.738	0.613	G = - 0.321
FL-III	-2.457	-1.375	0.047	J = 0.333
Constant	-7.495			
Sectioning Point	0.006			
Function 2 (Breadth Variables)				
FB-I	-5.420	-0.787	-0.478	
WB	2.079	0.695	0.448	G = 0.463
PB	0.964	0.531	0.392	J = -0.481
FB-V	-3.208	-0.387	-0.269	
Constant	-3.201			
Sectioning Point	-0.009			
Function 3 (Index Variables)				
PI	0.194	1.000	1.000	G = 0.267
Constant	-15.531			J = -0.277
Sectioning Point	-0.005			
Function 4 (Finger Variables)				
FB-I	4.870	0.707	0.562	
FL-IV	2.847	1.368	0.498	G = -0.395
FL-III	-2.008	-1.124	0.038	J = 0.410
FB-II	-3.716	-0.424	0.084	
Constant	-8.533			
Sectioning Point	0.0075			
Function 5 (Hand Shape Variables)				
WB	2.122	0.709	0.387	
HL	-0.667	-0.630	-0.219	G = 0.537
PB	6.904	3.802	0.338	J = - 0.558
MHB	-5.797	-3.623	0.193	
Constant	3.352			
Sectioning Point	-0.0105			
Function 6 (All Hand Variables)				
PI	0.085	0.437	0.444	
FB-I	-4.590	-0.666	-0.369	G = 0.601
WB	2.186	0.730	0.346	J = -0.624
FL-IV	-2.072	-0.996	-0.327	
FL-III	1.345	0.753	-0.021	
Constant	-4.745			
Sectioning Point	-0.0115			

Table 5: Canonical discriminant function coefficients and sectioning points for hand variables selected by the stepwise sub-routine for females.

Functions and Variables	Unstandardized coefficient	Standardized Coefficient	Structure Coefficient	Gujar and Jat group centroids
Females[a]				
Function 1 (Length Variables)				
FL-I	2.296	1.000	1.000	G = 0.114
Constant	-13.821			J = -0.120
Sectioning Point	-0.003			
Function 2 (Breadth Variables)				
WB	-6.129	1.212	0.803	G = 0.284
FB-III	4.031	-0.724	-0.037	J = -0.299
Constant	-9.938			
Sectioning Point	-0.0075			
Function 3 (Index Variables)				
PI	0.186	1.000	1.000	G = 0.127
Constant	-14.569			J = -0.133
Sectioning Point	-0.003			
Function 4 (Finger Variables)				
FL-I	2.296	1.000	1.000	G = 0.114
Constant	-13.821			J = -0.120
Sectioning Point	-0.003			
Function 5 (Hand Shape Variables)				
WB	3.802	1.143	0.744	G = 0.306
HB-II	-1.235	-0.584	-0.065	J = -0.322
PL	-0.778	-0.462	-0.240	
Constant	-3.522			
Sectioning Point	-0.008			
Function 6 (All Hand Variables)				
WB	2.744	0.825	0571	
FB-III	-3.804	-0.449	-0.027	
FL-IV	-0.970	-0.473	-0.141	G = 0.399
PB	1.465	0.687	0.312	J = -0.420
FL-I	1.144	0.498	0.285	
HB-II	-1.027	-0.485	-0.050	
PL	-0.635	-0.378	-0.184	
Constant	-5.362			
Sectioning Point	-0.0105			

In case of North Indian females of Gujars and Jats, thumb finger length made the greatest contribution in Function 1; wrist breadth made the greatest contribution followed by middle finger breadth in Function 2; palm index in Function 3; finger breadth at proximal inter-phalangeal joint of the index made the greatest contribution in Function 4 followed by finger breadth at thumb, middle and finger length at thumb contributes the least; in Function 5 wrist breadth made the greatest contribution followed by hand breadth – II and palm length contributes least in the function and lastly in Function 6, wrist breadth again made the greatest contribution followed by palm breadth, thumb finger length, hand breadth – II, ring finger length, middle finger breadth and palm length contributes the least in function for discrimination analysis.

The structure coefficient determines the correlation between the variables and the function. Here, palm index had the highest correlation in function 3 & 6 and finger breadth at proximal inter-phalangeal joint of the thumb in function 2 & 4 in males of north Indian Gujars and Jats. In case of females, wrist breadth had the highest correlation in functions i.e. in function 2, 5 & 6.

The unstandardized or raw coefficients are used for calculating the discriminant function scores for all the functions from the raw data and the score acts to determine or weigh the variable according to its contribution to ethnicity difference. A discriminant score is obtained by multiplying each variable with its raw coefficient and then adding them together with the constant.

The discriminant score is then compared with the sectioning point. If the number of cases in groups are same, then the constant has no inherent value and only serve to calibrate the sectioning point to zero but if the number of cases in groups differ (as in the research study for all the functions), the sectioning point must be calculated by averaging the two group centroids as shown in Table 4 & 5. For example, in function 1 & 4 in case of males, a discriminant score greater than the sectioning point (0.006 for function 1; -0.533 for function 4) classifies as Jat and for the functions 2, 3, 5 & 6, a discriminant score greater than the sectioning point classifies as Gujar. In case of females for all the functions, a discriminant score greater than the sectioning point (-0.003 for function 1; -0.0075 for function 2; -0.003 for function 3 & 4; -0.008 for function 5; -0.0105 for function 6) classifies as Gujar.

Raw coefficients also used to calculate the discriminate equation for all functions. To calculate a discriminant equation from a function, each variable of a function is multiplied with its unstandardized coefficient and then all of them are added together along with the constant as shown in Table 6.

Table 6: Discriminant equations for discriminating ethnic groups (Gujars and Jats).

Functions	**Discriminant equations**
Males	
Function 1	**D** = 3.616 (FL-IV) – 2.457 (FL-III) – 7.495
Function 2	**D** = -5.420 (FB-I) + 2.079 (WB) + 0.964 (PB) – 3.208 (FB-V) – 3.201
Function 3	**D** = 0.194 (PI) – 15.531
Function 4	**D** = 4.870 (FB-I) + 2.847 (FL-IV) – 2.008 (FL-III) – 3.716 (FB-II) – 8.533
Function 5	**D** = 2.122 (WB) – 0.667 (HL) + 6.904 (PB) – 5.797 (MHB) + 3.352
Function 6	**D** = 0.085 (PI) – 4.590 (FB-I) + 2.186 (WB) – 2.072 (FL-IV) +1.345 (FL-III) – 4.745
Females	
Function 1	**D** = 2.296 (FL-I) – 13.821
Function 2	**D** = -6.129 (WB) + 4.031 (FB-III) – 9.938
Function 3	**D** = 0.186 (PB) – 14.569
Function 4	**D** = 2.296 (FL-I) – 13.821
Function 5	**D** = 3.802 (WB) – 1.235 (HB-II) – 0.778 (PL) – 3.522
Function 6	= 2.744 (WB) – 3.804 (FB-III) – 0.970 (FL-IV) +1.465 (PB) + 1.144 (FL-I) – 1.027 (HB-II) – 0.635 (PL) – 5.362

Multivariate and cross-validation classifications for correct group membership are presented in Table 7. The classification accuracy ranged from 51.9% to 72.8%. Multivariate accuracies are very high in the stepwise discriminant function when all variable entered in the function (Function 6), reaching 75% and 66% for males and females respectively. Breadth variables also proved to be racially dimorphic (Function 2) ranging from 74% (males) and 64% accuracy (females). The table also shows cross-validation percentages after using the leave-one-out classification. It is evident that the results were not considerably different from the multivariate discrimination classification. The classification accuracy was higher for males than females.

Posterior probability of correct group membership increases with increases in distance from the sectioning point. A set of intervals was constructed in order to measure posterior probability as shown in Table 8. It is clear that the majority of the individuals in both the sex groups had 60% or more posterior probability of being member of their original population group. For example in Function 1, of correctly classified males, 91% of Gujars and 92% of Jats had a posterior probability of more than 60% to be a member of their actual Gujar and Jat populations respectively in case of females. Corresponding figures are less for the males and for the other functions.

Table 7: Racial classification accuracy for the hand variables.

Functions	**Total**	**Gujar**		**Jat**		**Average**
	N	***%***	***N***	***%***	***n***	***%***
Multivariate discrimination						
Males						
Length Variables	316	67.7	109/161	58.7	91/155	63.3
Breadth Variables	316	73.9	119/161	61.9	96/155	68.0
Index Variables	316	62.1	100/161	57.4	89/155	59.8
Finger Variables	316	69.6	112/161	61.9	96/155	65.8
Hand Shape Variables	316	73.9	119/161	68.4	106/155	71.2
All hand Variables	316	**74.5**	120/161	**71.0**	110/155	**72.8**
Females						
Length Variables	312	62.5	100/160	40.8	62/152	51.9
Breadth Variables	312	63.8	102/160	61.2	93/152	62.5
Index Variables	312	61.9	99/160	48.0	73/152	55.1
Finger Variables	312	62.5	100/160	40.8	62/152	51.9
Hand Shape Variables	312	62.5	100/160	62.5	95/152	62.5
All hand Variables	312	**66.3**	106/160	**72.4**	110/152	**69.2**
Cross-validation						
Males						
Length Variables	316	67.7	109/161	58.1	90/155	63.0
Breadth Variables	316	73.9	119/161	60.6	94/155	67.4
Index Variables	316	62.1	100/161	57.4	89/155	59.8
Finger Variables	316	67.7	109/161	61.3	95/155	64.6
Hand Shape Variables	316	73.9	119/161	68.4	106/155	71.2
All hand Variables	316	**73.9**	119/161	**69.7**	108/155	**71.8**
Females						
Length Variables	312	62.5	100/160	40.8	62/152	51.9
Breadth Variables	312	63.8	102/160	61.2	93/152	62.5
Index Variables	312	61.9	99/160	48.0	73/152	55.1
Finger Variables	312	62.5	100/160	40.8	62/152	51.9
Hand Shape Variables	312	62.5	100/160	61.8	94/152	62.2
All hand Variables	312	**65.6**	105/160	**70.4**	107/152	**67.9**

DISCUSSION

One of the key roles of the forensic anthropologists is to determine ethnicity of unknown evidences and thus continuous research has been conducted to achieve optimum results.[24,26,34,35] The hand variables were found to differ in males and females in terms of robusticity due to differential growth pattern and thus were extensively utilized for stature and sex prediction.[3,6,20,23,36] Population specific discriminant formulae also have been published for many populations across the world for stature and sex with increased rates of accuracy.[11,13,37,41] However, there is limited number of study concerned with ethnicity identification and thus the present study made an attempt to identify ethnicity from hand variables and also there is a requirement towards constantly updating the existing standards in order to account for secular changes.[41]

Table 8: Percentages of posterior probability intervals of correct classification for North Indian Gujars and Jats.

Probability intervals	Male		Female	
	Gujar	***Jat***	***Gujar***	***Jat***
Function 1				
0.00 – 0.19	1.9	2.2	-	-
0.20 – 0.39	16.1	27.5	2.9	3.5
0.40 – 0.59	51.6	49.7	**90.7**	**92.3**
0.60 – 0.79	28.2	18.1	6.4	4.2
0.80 – 1.00	2.2	2.5	-	-
Function 2				
0.00 – 0.19	9.2	6.3	-	2.6
0.20 – 0.39	19.3	32.3	17.9	19.5
0.40 – 0.59	29.1	31.7	54.9	54.5
0.60 – 0.79	34.8	18.9	24.6	22.8
0.80 – 1.00	7.6	10.8	2.6	0.6
Function 3				
0.00 – 0.19	0.6	1.6	-	-
0.20 – 0.39	18.4	18	2.6	9.6
0.40 – 0.59	57.3	57.6	**85.2**	**87.5**
0.60 – 0.79	22.1	21.9	12.2	2.9
0.80 – 1.00	1.6	0.9	-	-
Function 4				
0.00 – 0.19	4.4	5.1	-	-
0.20 – 0.39	20.6	30	2.9	3.5
0.40 – 0.59	38.9	38.3	**90.7**	**92.3**
0.60 – 0.79	31	21.5	6.4	4.2
0.80 – 1.00	5.1	5.1	-	-
Function 5				
0.00 – 0.19	12.3	13.6	-	2.9
0.20 – 0.39	19	27.2	25.6	22.7
0.40 – 0.59	27.2	26.6	46.2	45.6
0.60 – 0.79	26.9	19	25	28.5
0.80 – 1.00	14.6	13.6	3.2	0.3
Function 6				
0.00 – 0.19	15.5	16.5	2.9	8.0
0.20 – 0.39	19.6	21.5	26.9	22.4
0.40 – 0.59	24.4	26.6	37.8	37.8
0.60 – 0.79	21.5	19.0	23.4	28.5
0.80 – 1.00	19.0	16.5	9.0	3.2

This research has resulted in the development of effective anthropometric standards for distinguishing north Indian Gujars and Jats with the help of stepwise discriminant function analysis. The main advantage of the technique is that it reduces subjective judgement needed for identification of ethnicity. The results of the research study showed that hand can be used for determination of ethnicity upto an overall accuracy of 72.8% using all the hand variables with Gujar having 74.5% accuracy and Jats having 71% in case of males whereas in case of females the overall accuracy was 69.2% with Gujars having 66.3% ad Jats having 72.4%. It is evident in the research that cross-validation tests using the leave-one-out classification represent realistic and unbiased estimates and were not considerably different from the multivariate discrimination classification. Breadth variables provide accuracy ranging from 73.9% in males and 61.9% in females and thus proved to be more racially dimorphic than length variables. This is supported by studies which suggest that breadth variables provide better separation of sexes than length.[41] The classification accuracy ranged from 51.9% to 72.8% and the prediction accuracy is higher among males than females. The stepwise discriminant function equations so obtained may be utilized in forensic and archaeological situations where recovered hands may be incomplete or show signs of damage. However, the results so obtained cannot be compared with the results from different populations as there is no such study conducted on ethnicity identification from hand dimensions. Thus it is suggested that more studies should be conducted on this issue to shed more light towards its prediction power.

In conclusion, we propose that hand is one of the most frequently encountered bone recovered in forensic cases.[2,23] The results of the present study demonstrate high accuracy rates for the determination ethnicity from the hand measurements in North Indian populations. The study produced discriminant function formulae that accurately classify remains of unknown ethnic group. This study also highlights the need for population specific discriminant function equations for ethnicity identification. Since combinations of variables provided a higher level of accuracy than individual variables, they should therefore be used when available. Future research in this direction is needed and should be conducted in the same or different ethnic groups so that population specific formulae could be derived and can be utilized to discriminate or identify ethnic groups in anthropology and forensic scenarios.

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